Physical Properties of LWC Papers and Gravure Ink Mileage

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Abstract

Paper properties, such as roughness, air permeability, pore size and their relationships to the ink mileage were studied. Ink mileage was measured using commercial toluene based gravure coated inks marked with trace metal carboxylates, which can be detected after printing by means of Inductively Coupled Argon Plasma (ICAP/ICP) Atomic Emission Spectroscopy (AES). Magenta ink was doped with one metal carboxylate, while cyan and black inks were doped with another metal carboxylate. The amount of ink transferred was calculated from the ICP analysis of both wet ink and printed samples. Commercial LWC coated papers for rotogravure were used as testing substrates. Paper surface properties studied were air permeability (Parker Print-Surf (PPS) porosity), mercury intrusion porosimetry, and surface roughness, measured by PPS, Emveco stylus profilometer and Atomic Force Microscopy (AFM). It was found that compressed cells transferred more ink than elongated and normal cells. Paper porosity, permeability and pore size have more profound effects than surface roughness on amount of ink transferred to paper. However, the correlations between surface properties and ink transfer are not as clear as expected. Possible reasons could be the interaction between surface roughness and pore properties, or other unknown factors such as coating formulation and structure.

Introduction

It is always a goal for printers to achieve desired print quality with little consumption of printing inks. Ink requirement is defined as the quantity of ink needed per unit paper surface area to attain a specific level of relative print density. Ink mileage (Serafano, 1998) expressed as the number of square meters covered by a kilogram of ink is conceptually the opposite of ink requirement (Oittinen and Saarelma, 1998). Variation in the ink film thickness affects ink density. Uneven contact between the ink layer and the paper surface is a reason for variation of ink film thickness (Eldred, 2001), and thus ink optical density,

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also known as print mottle. In rotogravure printing, ink spreading and penetration happen within a fraction of a second. The ink behavior on the surface of paper has been found to depend mainly on roughness and permeability (Serafano, 1998, Picollet et al, 1998). Therefore, it is very important to understand how these properties affect the ink mileage.

Ink estimating charts have been used for many years to make the calculation of ink consumption (Silver, 1984). These charts are based on the approximate number of thousand square inches that can be printed with a pound of a particular type of ink on a particular type of paper. In offset printing, the amount of ink transferred to paper is determined by weighing the amount of ink in ink pan before and after printing. The corresponding print density is measured. Print density vs. the amount of ink is plotted in a graph from which the ink requirement at any give point can be determined. For gravure, a similar technique is not applicable. Solids content in solvent-based gravure ink is about 30% of the weight, thus the weight of the ink film compared to variation of substrate grammage is too small to achieve reliable results. Currently, the method for measuring ink mileage on a gravure press is weighing the amount of the ink in the ink fountain before and after a printing job. This method is inaccurate, and inconvenient, because of the large uncertainty in the amount of evaporated solvent. Therefore, we used a different method. In this method the ink is doped with a tracer not originally present in the ink or paper, which can be measured analytically. Metal carboxylates, used as sheet-fed ink drying additives, were found to be conveniently available (Shepherd, 2005a). Metal ions can be easily detected analytically using Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy (AES) (Boumans, 1987). The concentration of the tracer in the ink must be low enough not to affect ink performance or color shade.

The objective of this work was to study the paper properties, such as roughness, porosity, pore size and volume and their relationship to gravure ink mileage.

Experimental

Paper Substrates

The papers used were five commercial LWC coated papers for rotogravure with basis weight of 53.9 g/m^2. No information about their coating formulations was available.

Roughness Measurement

Three methods of roughness measurement were employed: Parker Print-Surf (PPS) (TAPPI, 1999), an EMVECO stylus profilometer (Enomae and Lepoutre, 1995), and an Atomic Force Microscope (AFM) (Béland and Bennett, 2000, Dalton et al., 2002, Strőm et al., 2003, Myshkin et al., 2003, and Xu et al., 2004). These methods were previously seen to be valuable in characterizing ink jet papers and ink films (Xu et al., 2004).

A PPS Model 90 (Messmer Instrument) was used at a pressure of 1000 kPa with hard backing. The roughness [µm] was calculated as the mean of 10 readings at different substrate locations.

An Electronic Microgage Model 210-R (EMVECO, Inc) with the spherical steel stylus having a radius of 1 µm was used for profilometer measurement. The test conditions were 500 readings per group, 3 groups, 0.1 mm reading space, and 0.5 mm/s scanning speed. The roughness R was calculated using:

$$R = \Sigma (X_{i+1} - X_i)/499, i = 1,2,\ldots,499 \qquad (1)$$

The AFM measurements were made using an Autoprobe CP, Scanning Probe Microscopy (Park Scientific Instruments) with Proscan software version 1.3. The tapping mode was used with a silicon tip of 20 nm in diameter. The samples were attached to the sample holder with double-sided tape. Topographic data were obtained over a 20 µm × 20 µm area. The scanning rate was 0.5 Hz. All images were flattened, i.e., the mean plane of the height distribution was subtracted from each image. The roughness values were reported as the root-mean-square (rms) deviation [nm] of the surface heights from the mean surface plane.

Air Permeability Measurement

The Parker Print-Surf instrument was used to measure air permeability (PPS porosity) of the papers at a clamping pressure of 500 kPa. The PPS porosity can be used to determine the actual air permeability of a paper sample (Pal et al., 2005).

Pore Size and Volume Measurement

Pore size distributions were determined by mercury porosimetry (Lee et al., 2005). Measurements were carried out using an Autopore IV 9500 (Micromeritics Instrument). Paper samples of approximately 10 cm^2 were placed in a penetrometer and evacuated at 50 µm Hg for 5 minutes immediately before measurement.

Printing Procedure

The papers were printed on a four color Cerutti rotogravure web press located at Western Michigan University (WMU) Printing Pilot Plant. Commercial toluene-based coated inks for rotogravure (Flint Ink) were used. The ink efflux time with

Shell cup #2 was kept at 22 ± 0.3 seconds for yellow, magenta, and cyan inks and 20 ± 0.3 seconds for black ink, by frequent addition (every 15 minutes) of toluene during the printing process. Liquid ink samples were collected in the beginning, middle and end of the trial. Two metal carboxylates were chosen as the tracers based on recommendations from Shepard Chemicals (Shepherd, 2005b) for compatibility with toluene based inks. ICP-AES is known to be very accurate for metals (ORNL, 2005). The amounts of the metals required for accurate detectibility were obtained on consultation with Guelph Chemical Laboratories Ltd. (Guelph, 2005). The two metals used in the three inks are shown in Table 1.

Table 1: Trace metals used in inks

Ink Color	Tracer Solution	Concentration in Ink [wt%]
Magenta	Metal A	>> Detectibility limit
Cyan	Metal B	>> Detectibility limit
Black	Metal B	>> Detectibility limit

The electromechanically engraved cylinders have different cell types and screen values, shown in Table 2.

Table 2: Cylinder engraving information

Cylinder	Cell Type	Screen [lpi]
Magenta	Elongated	175
Cyan	Compressed	175
Black	Normal	225

Both sides of the papers were printed, but not at the same time to avoid sidedness effects of the press. The target ink optical densities were 1.3 for magenta, 1.25 for cyan, and 1.50 for black. Printing was done at 1000 ft/min with electrostatic assist (ESA) on.

ICP Analysis

Both wet ink samples and solid areas of printed samples were analyzed at Chemisar Laboratories, Inc., Guelph, CA. By knowing the amount of tracer metal in both the wet ink and printed ink film, the mass of ink transferred to the printed area can be calculated by using:

$$\text{Ink transfer (gsm)} = \text{Tracer in print sample (gsm)} / \text{Tracer in ink (wt\%)} \quad (2)$$

Results and Discussion

The concentrations of the tracing metals in the liquid inks for printing were measured by ICP/AES and used for mileage calculations.

Five LWC papers were printed from both sides, totaling 10 samples. They were designated as No. 1-10. The average value of tracing metal concentration was used for calculation of ink transfer according to equation (2). The calculated ink amount transferred to the papers [g/m^2] for each color is shown in Table 3.

Table 3: Ink amounts transferred to papers calculated according to equation (2)

Sample	No.	Magenta		Cyan		Black	
		g/m^2	error	g/m^2	error	g/m^2	error
LWC#1	1	2.78	0.087	3.18	0.063	2.29	0.161
	2	2.75	0.087	3.66	0.073	2.52	0.177
LWC#2	3	2.87	0.090	3.87	0.077	2.57	0.181
	4	1.64	0.052	3.63	0.072	2.65	0.187
LWC#3	5	2.91	0.091	3.89	0.078	2.56	0.180
	6	2.63	0.083	3.99	0.080	2.59	0.182
LWC#4	7	2.35	0.074	4.00	0.080	2.54	0.179
	8	3.62	0.114	3.80	0.076	2.49	0.175
LWC#5	9	2.73	0.086	3.88	0.077	2.63	0.185
	10	2.68	.084	3.71	0.074	2.94	0.207

The ink amounts transferred onto LWC papers for three different inks and three different cell geometries are shown in the Figure 1. More cyan ink was transferred than magenta and black inks on all of the LWC papers, which probably means that compressed cells transferred more ink than elongated and normal cells. Differences in ink transfer between compressed and elongated gravure cells were reported by Khandekar (2000).

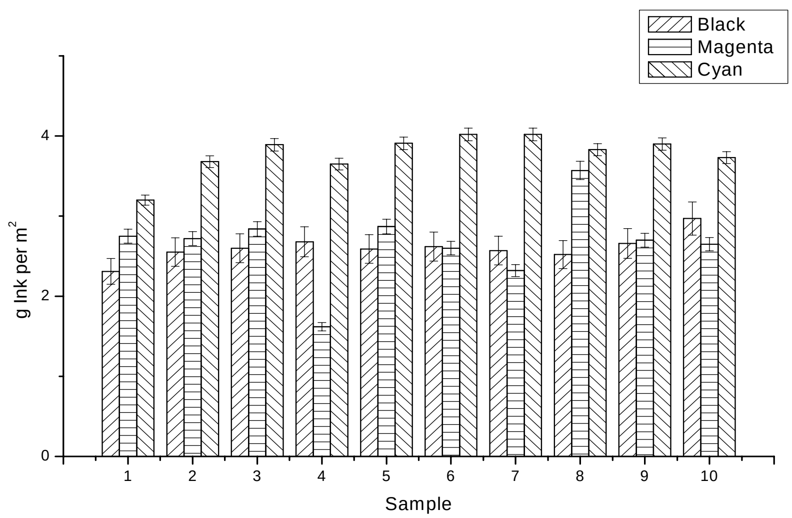

Figure 1: Ink transfer on both sides of different LWC papers.

The results of paper surface roughness are listed in Table 4. Overall, LWC#5 was rougher than the rest of the tested LWC substrates. AFM images of the smoothest and roughest sample, sample No. 5 and No. 10, are shown in Figure 2. The image on the right (No. 10) looks much rougher than the No. 5, which was confirmed by AFM.

Table 4: Comparison of LWC paper roughness measured by different methods

Sample	No.	PPS H10 [µm]	Emveco [nm]	AFM [nm]
LWC#1	1	1.56	59.6	40.16
	2	1.45	61.9	44.83
LWC#2	3	1.43	56.4	31.95
	4	1.45	54.5	44.11
LWC#3	5	1.37	49.3	29.89
	6	1.53	54.7	35.05
LWC#4	7	1.55	61.2	34.90
	8	1.60	64.2	40.43
LWC#5	9	1.85	63.6	74.49
	10	1.76	62.0	76.49

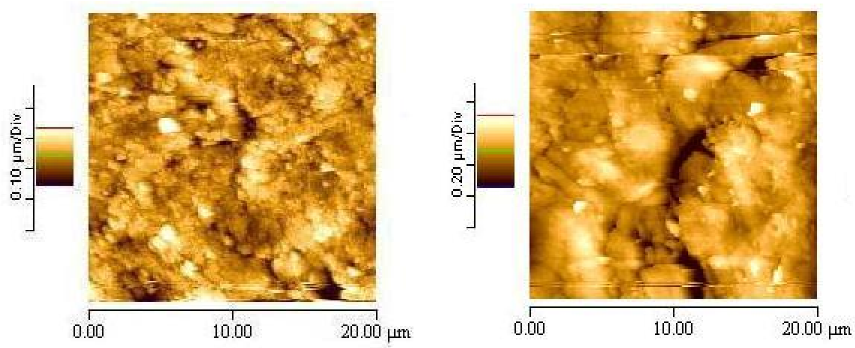

Figure 2: AFM images of sample No. 5 (left) and No. 10 (right).

Figures 3-5 show relations between ink transfer and roughness obtained by three different methods. There was no strong correlation found between roughness and ink transfer.

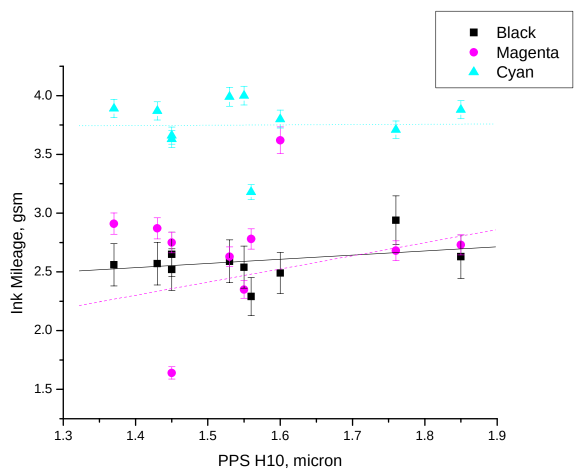

Figure 3: Relationship of ink transfer vs. paper PPS roughness.

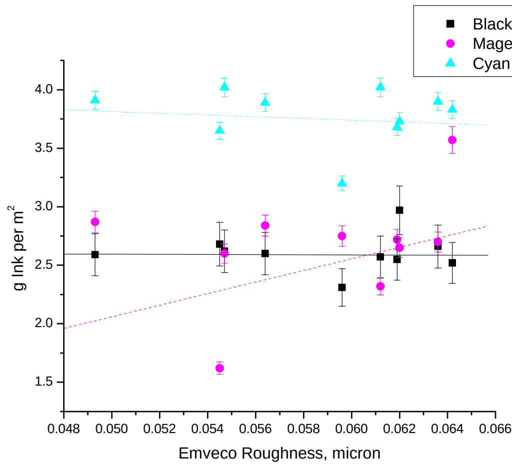

Figure 4: Relationship of ink transfer vs. Emveco roughness.

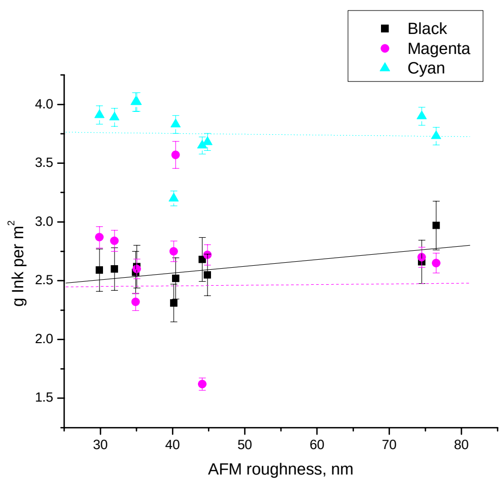

Figure 5: Relationship of ink transfer vs. AFM roughness.

Figure 6 shows the relation between ink transfer and PPS porosity. Ink amount transferred to paper increased very slightly with higher PPS porosity.

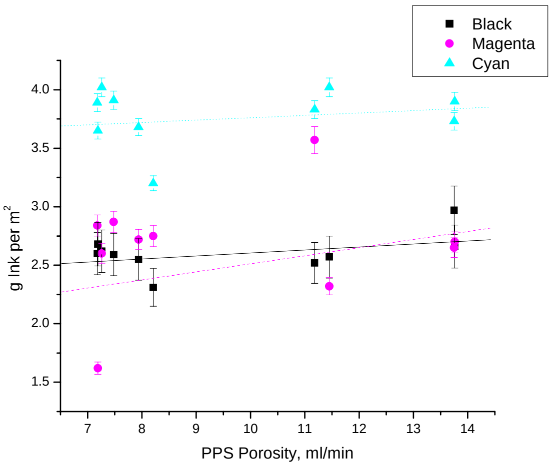

Figure 6: Relationship of ink transfer vs. PPS porosity

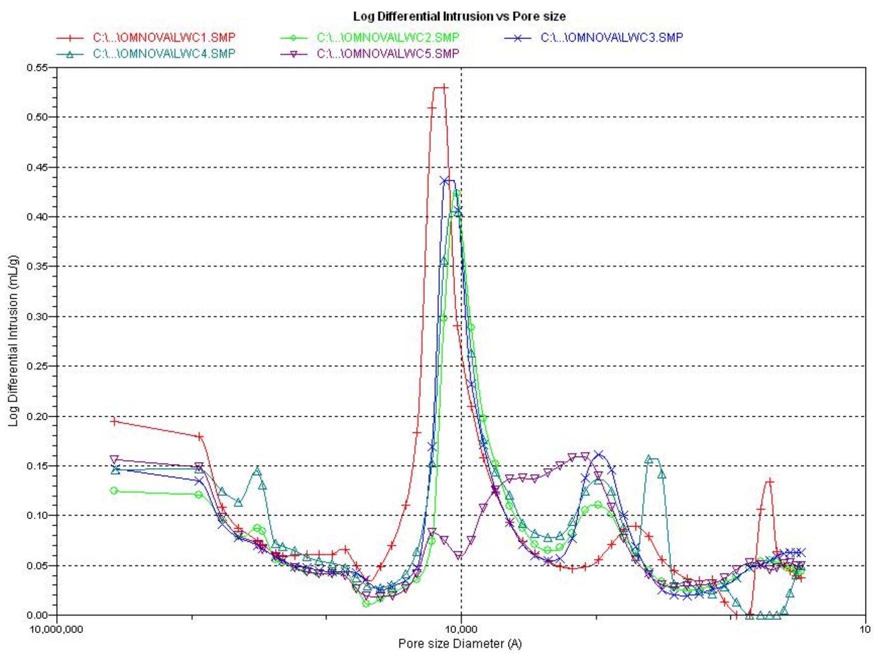

Figure 7: Distribution of pores in LWC substrates measured by mercury porosimetry.

Mercury porosimetry curves in Figure 7 show the pore size distribution of LWC substrates. The *x,y* axis were chosen so that the area under the curve is equal to the pore volume. Papers LWC#1 to LWC#4 all have peaks of pore sizes at about 1 μm. LWC#5 has smaller pores between 1 μm to 100 nm. LWC#4 has some large pores with size of several tens of microns.

Average pore diameters can be calculated from mercury porosimetry curves, which are shown in Table 5. As discussed above, LWC#4 has biggest average pore size, while LWC#5 has the smallest one. Large pores can be seen in the AFM image of sample LWC#4 (Figure 8), whose pore size is in the range of microns.

Table 5: **Average Pore Size**

Sample	Average Pore Diameter [nm]
LWC#1	74.4
LWC#2	65.0
LWC#3	63.7
LWC#4	135.2
LWC#5	59.1

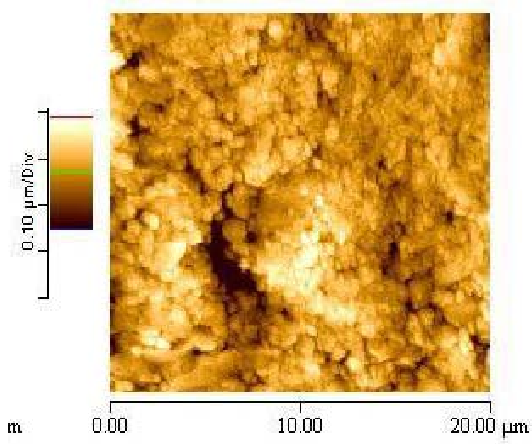

Figure 8: AFM image of LWC#4

Figure 9 shows the relation between ink transfer and average pore size. With increasing pore diameter, ink transfer for magenta and cyan ink/cell geometry increases.

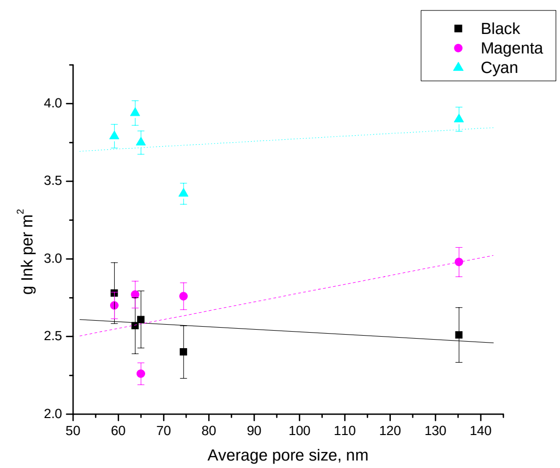

Figure 9: Ink transfer vs. average pore size.

Conclusions

Inductively coupled plasma (ICP), combined with atomic emission spectroscopy (AES) is a convenient analytical method that can be used to measure gravure ink consumption and ink film weight. Cyan ink, printed from compressed cells, transferred more ink than magenta (from elongated cells) and black (from normal cells). Paper permeability and pore size had more profound effects on ink transfer than surface roughness. The correlations between surface properties and ink transfer were not clear. Possible reasons for this could be the interactions between roughness and porous substrate properties, or other unknown factors such as coating formulations and chemical nature of the ingredients of coating structures. Further study can be done with controlled coating formulation, and/or different grades of paper.

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